Ministry of
Transportation and
Communications

Ontario

REPORT EM-49

STRENGTH PRODUCING PROPERTIES OF PORTLAND CEMENTS USED IN ONTARIO

Engineering
Materials
Office

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By

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July, 1981

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SUMMARY

Portland cements (Type 10) from seven sources were tested for their effect on i) the compressive strength of 20, 30 and 35 MPa class of concrete and ii) the air content of non-air entrained and air entrained concrete.

It was found that the differences in the strength producing properties of the cements were not too excessive, although one of the cements produced significantly lower 3d strength than any of the others. Concrete made with two of the seven cements required substantially less air entraining admixture to entrain the specified amount of air. The report recommends that field concrete made with these two cements be checked for the adequacy of its air void system.

INTRODUCTION

There have been intermittent reports that some ready mix plants experience substantial differences between the strengths of concrete made with cements of the same type from different sources. In one case, in 1980, a decrease in the strength of 30 MPa class of concrete to an unacceptable level was attributed to such a change.

This Ministry's current policy is to specify only cement content and type of cement. The cement must be from one of the sources shown by the Ministry in its Designated Sources List DS:136. The list designates sources whose cements are periodically tested by the Ministry and comply with the minimum requirements of CSA Standard CAN3-A5-M77. The strength properties of these cements (Table A), as measured by the standard mortar cube test, differ substantially. Therefore, it is expected that there would be differences between the strengths of concrete made with these cements. If the differences are significant, they should be taken into consideration in the mix proportioning particularly for higher classes of concrete.

There are also indications that the source of cement has a significant effect on the air content of non-air entrained concrete and on the amount of air entraining admixture required to obtain the specified air content in air entrained concrete. If this is true, some cements may have an adverse effect on the air void system and durability of the concrete.

This report describes a laboratory investigation into the differences between the cements listed in DS:136. It was carried out during the winter of 1980/81.

OBJECTIVES

The objectives of this project were to determine:

i) differences between the strength producing properties of Type 10 cements approved by the Ministry

ii) differences between the effects of the cements on the air content of concrete

CEMENTS TESTED

Type 10 cements from seven sources (mills) were included in the program. Only one of the cements was from outside Ontario. The chemical and physical properties of the cements are shown in Table B and C, respectively. All of them complied with the requirements of MTC Form 1301 (CSA Standard CAN3-A5-M77).

Samples of the cements were obtained by this Ministry's Regional Quality Assurance staff from the cement mills or ready mix plants.

CONCRETE MIXES

Each cement was tested in three series of mixes using the aggregates described in Table D. One of the series was a 20 MPa class non-air entrained concrete (Table E) and the other two were a 30 MPa (Table F) and 35 MPa (Table G) class air entrained concrete. The air entrained concrete contained a water reducing admixture complying with the requirements of MTC Form 1303 for Type WN. The air entraining agent was of the organic salts of sulphonated hydrocarbon group. All mixes were proportioned to produce a slump of 80±10 mm. The air content of the air entrained mixes was 6±0.5% as measured by the pressure meter.

The concrete was mixed in a pan type mixer. All tests of the fresh and hardened concrete were in accordance with the appropriate test methods of CSA Standard CAN3-A23.2-M77.

TEST RESULTS

It is evident from Table E that there are differences between the air contents of the seven non-air entrained mixes. The mix containing cement E had the highest air content (5.4%), at least 0.9 percentage points higher than any of the other six mixes (3.8-4.5%). Air entrained mixes (Table F and G) made with this cement required a considerably smaller dosage of the air entraining admixture than any of the other mixes with the exception of the mix with cement G. Table C shows that cement E and G produced the highest air contents in the standard mortar (ASTM C185-75). It is seen from Figure 1 that there is a relatively good relationship between the air contents of the standard mortar and the amount of the air entraining admixtures per batch of concrete to entrain an air content of 6±0.5% and that the two cements required the smallest amount of the air entraining admixture.

The strength test results are shown in Tables E, F and G, and illustrated in Figure 2 to 4. The concrete with cement G produced the lowest 3d compressive strength in each of the three series of mixes (Figures 2 to 4). The strength was from 9.3 to 25.4 percent lower than the average strength of all the mixes in the series. The differences between the strengths were considerably reduced at later ages than 3d and no mix produced a strength that differed more than 7.0 percent from the average strength of all the mixes in the series with the exception of the air entrained 35 MPa mix with cement G at 7d. The mix produced 9.2 percent lower strength. In some cases, lower or higher strength can be at least partially attributed to a higher or lower air content and/or slump. However, the air entrained 30 MPa mixes (Table F) were very consistent in slump (75 to 85 mm) and air content (6.0 to 6.5%) and the 3d strength of the mix with cement G was still 9.3 percent lower than the average strength.

Figures 5 and 6 show the relationship between the standard mortar cube strengths (CSA CAN3-A5-M77) and the standard cylinder concrete strengths. It is evident from these two graphs and from Table C that cement G produces lower mortar and concrete strengths than any of the other cements. The graphs show a good relationship between the standard mortar and the concrete strengths.

TESTS BY NORTHWESTERN REGIONAL LABORATORY

The Ministry's Northwestern Regional Laboratory tested strength producing properties of cement E and G in 1980. The tests were carried out under the supervision of Mr. Ken Maundrell. The cements were tested in 20 and 30 MPa class of air entrained concrete using local aggregates. Figure 7 illustrates the strength obtained with the two cements and shows that the concretes made with cement G had substantially lower strength than those made with cement E. There was also substantially lower strength of the standard mortar made with a sample of cement G (3d 19.2 MPa, 7d 24.8 MPa) than that of the standard mortar made with a sample of cement E (3d 24.4 MPa, 7d 30.9 MPa) used in the concrete mixes.

CONCLUSIONS

The tests carried out in the Downsview Laboratory and described above show that:

1) Cement G produced lower strength than any of the other six cements tested. The difference lessened with an increase in age of the concrete. It was up to 25.4 percent at 3d and up to 9.2 percent at later ages of the average strength of the series.

2) The 7d or later strength of concrete made with any of the seven cements did not differ from the average strength of all mixes of the same series and of the same age by more than 7.0 percent with the exception of cement G, 35 MPa mix at 7d which differed by 9.2 percent.

3) No two mixes of the same series and an age of at least 7d differed in their compressive strength by more than 12.2 percent of the series average with the exception of the mix with cement G.

4) The non-air entrained mix made with cement E showed significantly higher air content than any of the other mixes in the series (made with any of the other cements). Air entrained mixes made with cement E and G required substantially lower amounts of the air entraining admixture to obtain the specified air content.

5) There is a good relationship between the standard mortar cube strength and the standard concrete cylinder strength.

GENERAL COMMENTS AND RECOMMENDATIONS

All other factors being constant, concrete compressive strength depends on the strength producing properties of the cement. There is variation in the strength producing properties of cements from different sources and there is also variation between batches of cement from the same source. The uniformity requirement of CSA Standard CAN3-A5-M77 is that "The coefficient of variation of the 28d compressive strength of Normal Portland cement shall not exceed 8.0 percent ...." and states that "The coefficient of variation shall be determined on the results of the 30 most recent consecutive samples taken from a single manufacturing source over a period not exceeding six months and tested at the same laboratory".

The maximum coefficient of variation for the 28d strength of any of the three series of concrete mixes made with cements from the seven different sources is only 4.4 percent. This is a small variation and cannot be considered excessive. All the cements tested are good quality products and may be used in all classes of concrete.

Since these tests showed that concrete made with cement E and G require relatively small amounts of air entraining admixture to obtain six percent air content, it is recommended that the air void system parameters of field mixed concrete be measured to determine the potential durability of such concrete.

TABLE A 28d Compressive Strength of Cements
1978-1980 *

Cement Plant	1978			1979			1980		
	No. of Samples (n)	Mean, MPa ($\bar{X}$)	Standard Deviation MPa (Sx)	No. of Samples (n)	Mean, MPa ($\bar{X}$)	Standard Deviation MPa (Sx)	No. of Samples (n)	Mean, MPa ($\bar{X}$)	Standard Deviation MPa (Sx)
A	33	33.5	2.1	5	35.8	3.1	14	36.0	3.2
B	42	33.4	2.3	16	33.0	2.2	13	34.4	1.9
C	14	34.2	2.3	9	35.0	3.1	10	35.5	1.7
D	30	36.0	2.2	12	35.8	3.9	6	35.7	1.9
E	38	31.4	2.0	9	30.9	3.7	15	34.7	4.5
F	29	31.2	2.2	14	33.0	2.3	9	31.1	4.3
G	7	36.3	2.2	8	37.7	3.7	3	36.9	4.1
H**	2	41.4	5.9	2	37.8	2.3	2	41.9	1.6

*) Tests carried out in accordance with CSA Standard CAN3-A5-M77.
**) This cement was not included in the concrete tests.

TABLE B Chemical Properties of Cements Tested

Cement Plant	A	B	C	D	E	F	G	CSA CAN3-A5-M77 Requirements
Lab. Sample No.	12/80	20/80	14/80	22/80	18/80	17/80	23/80	
Loss on ignition, %	1.88	1.49	1.49	0.99	1.10	2.11	1.90	max. 3.0
Insoluble residue, %	0.48	0.10	0.22	0.10	0.28	0.37	0.36	max. 0.7
C_3A, %	10.83	4.75	5.29	9.95	12.48	11.05	9.99	-
SO_3, %	3.76	3.43	3.11	3.19	3.35	2.85	2.87	$C_3A>8.0$ max. 3.5 $C_3A\leq 8.0$ max. 3.0
MgO, %	2.72	3.94	3.09	2.46	2.86	2.01	2.27	max. 5.0
Na_2O, %	0.25	0.41	0.52	0.30	0.18	0.10	0.19	-
K_2O, %	0.83	0.82	0.60	0.78	0.87	0.60	0.50	-
Alkali content, %	0.80	0.95	0.91	0.81	0.75	0.63	0.52	-
SiO_2, %	20.02	20.08	21.65	21.02	20.66	19.84	20.39	-
Al_2O_3, %	5.76	4.00	3.68	5.26	6.03	5.88	5.69	-
Fe_2O_3, %	2.62	3.46	2.64	2.36	2.07	2.68	3.01	-
CaO, %	62.16	62.37	63.22	63.64	62.94	63.78	63.18	-

Note: All properties determined in accordance with CSA Standard CAN3-A5-M77 with the exception of Na_2O, K_2O, SiO_2 and CaO. The latter properties were determined in accordance with ASTM C114-77.

TABLE C Physical Properties of Cements Tested

Cement Plant	A	B	C	D	E	F	G	CSA CAN3-A5-M77 Requirements
Lat. Sample No.	12/80	20/80	14/80	22/80	18/80	17/80	23/80	
Fineness								
-Ret. 75 μm, %	5.6	1.4	2.4	2.2	4.2	2.2	4.6	max. 82
-Blaine, m^2/kg	323.8	362.3	372.7	362.3	336.6	424.0	351.9	-
Normal consistency, %	23.7	25.9	22.9	23.8	25.5	25.9	23.8	-
Time of setting, min	90	105	85	100	110	85	80	45-360
Soundness, %	0.054	0.280	0.168	0.062	0.168	0.134	0.116	max. 1.0
Air content, %	7.0	6.0	6.7	6.4	8.1	7.5	10.2	
False set								
-paste method, %	-	-	-	-	-	60.7	-	-
-mortar method								
penetr. 11 min, mm	50	43	50	50	50	10	50	-
RM, mm	50	50	50	50	50	40	50	
Compr. strength, MPa								
3d	19.8	25.3	20.9	25.8	21.8	21.5	17.5	min. 12.5
7d	26.8	29.3	26.5	30.8	25.6	26.0	24.2	min. 18.0
28d	38.0	38.0	36.1	38.3	32.5	34.8	31.4	min. 26.5

Note: All properties determined in accordance with CSA Standard CAN3-A5-M77 with the exception of Blaine fineness, air content, false set by the paste method and false set by the mortar method which were determined in accordance with ASTM C204-79, C185-75, C451-75 and C359-75, respectively.

TABLE D Physical Properties of Fine and Coarse Aggregates

Aggregate	Fine	Coarse
Lab. Sample No.	79-B-12101 (Batch No. 74)	80-B-12013 (Batch No. 47)
Type	Natural sand	Crushed dolomitic limestone
Relative Density - Bulk - Apparent	 2.693 2.750	 2.655 2.763
Absorption	0.760	1.470
Gradation Sieve 19.0 mm 13.2 9.5 4.75 2.36 1.18 600 µm 300 150 75	% Passing 100 87.2 65.3 30.5 13.5 5.1 2.5	 100 67 34 0
Fineness modulus	2.98	-
Compact Density, kg/m^3 (CSA A23.2-10A)	-	1554

TABLE E Mix Proportions and Test Results
20 MPa Class Concrete, Non-Air Entrained

	Cement No.	A	B	C	D	E	F	G
	Lab. Mix No.	929/80	928/80	930/80	931/80	932/80	933/80	934/80
Batch Quantities	Fine Aggr., kg	45.5	45.5	45.5	45.5	45.5	45.5	45.5
	Coarse Aggr., kg	52.9	52.9	52.9	52.9	52.9	52.9	52.9
	Cement, kg	15.5	15.5	15.5	15.5	15.5	15.5	15.5
	Water, kg	9.60	9.50	9.55	9.50	9.60	9.60	9.80
	WRDA, mL	-	-	-	-	-	-	-
	DAREX AEA, mL	-	-	-	-	-	-	-
Test Results Fresh Concrete	Slump, mm	80	80	75	80	85	80	75
	Air Content, %	4.5	4.1	3.8	3.9	5.4	3.9	4.1
	Density, kg/m^3	2359	2366	2387	2380	2338	2380	2373
	Eff. w/c	0.548	0.542	0.545	0.542	0.548	0.548	0.561
	Cement, kg/m^3	296	297	300	299	293	299	297
Compressive Strength, MPa	3d	19.6 20.3 20.0	20.9 21.6 21.3	19.0 19.1 19.1	19.6 19.4 19.5	17.3 18.4 17.9	18.0 18.1 18.1	14.0 13.6 13.8
	7d	26.2 25.3 25.8	25.0 23.8 24.4	24.3 24.1 24.2	24.1 24.6 24.4	23.1 24.1 23.6	24.7 23.9 24.3	22.2 22.7 22.5
	28d	32.6 30.1 31.4	30.8 30.0 30.4	31.5 31.2 31.4	30.9 31.2 31.1	30.4 30.9 30.7	29.4 30.6 30.0	29.4 29.3 29.4
	90d	36.0 36.4 36.2	36.4 36.2 36.3	37.7 37.3 37.5	37.3 38.3 38.0	32.5 34.6 33.6	35.9 35.7 35.8	34.3 34.1 34.2

TABLE F Mix Proportions and Test Results
30 MPa Class Concrete, Air Entrained

	Cement No.	A	B	C	D	E	F	G
	Lab. Mix No.	937/80	936/80	938/80	939/80	940/80	941/80	942/80
Batch Quantities	Fine Aggr., kg	38.1	38.1	38.1	38.1	38.1	38.1	38.1
	Coarse Aggr., kg	52.9	52.9	52.9	52.9	52.9	52.9	52.9
	Cement, kg	17.8	17.8	17.8	17.8	17.8	17.8	17.8
	Water, kg	8.80	8.90	9.00	8.80	8.90	9.05	9.00
	WRDA, mL	78.3	78.3	78.3	78.3	78.3	78.3	78.3
	Darex AEA, mL	2.8	4.3	3.6	2.8	1.4	2.8	1.4
Test Results Fresh Concrete	Slump, mm	80	75	75	85	85	75	80
	Air Content, %	6.0	6.5	6.4	6.4	6.3	6.0	6.4
	Density, kg/m^3	2340	2333	2340	2344	2338	2331	2338
	Eff. w/c	0.433	0.438	0.444	0.433	0.438	0.447	0.444
	Cement, kg/m^3	354	353	353	355	354	352	353
Compressive Strength, MPa	3d	28.0 27.2 27.6	25.5 25.6 25.6	26.3 26.1 26.2	26.1 27.3 26.7	27.6 26.6 27.1	24.3 25.1 24.7	23.9 23.1 23.5
	7d	29.9 30.1 30.0	27.9 29.0 28.5	29.3 29.1 29.2	31.8 32.0 31.9	30.6 31.3 31.0	28.6 28.9 28.8	29.7 28.9 29.3
	28d	38.7 37.9 38.3	36.7 36.3 36.5	37.2 37.1 37.2	38.1 38.6 38.4	38.5 35.7 37.1	36.2 37.7 37.0	35.9 35.9 35.9
	90d	43.8 44.0 43.9	42.0 42.4 42.2	44.8 45.2 45.0	44.4 45.1 44.8	42.0 44.9 43.5	44.8 42.6 43.7	40.8 42.9 41.9

TABLE G Mix Proportions and Test Results
35 MPa Class Concrete, Air Entrained

Cement No.		A	B	C	D	E	F	G
Lab. Mix No.		944/80	943/80	945/80	946/80	947/80	948/80	949/80
Batch Quantities	Fine Aggr., kg	35.5	35.5	35.5	35.5	35.5	35.5	35.5
	Coarse Aggr., kg	52.9	52.9	52.9	52.9	52.9	52.9	52.9
	Cement, kg	20.8	20.8	20.8	20.8	20.8	20.8	20.8
	Water, kg	8.90	9.20	9.05	9.00	9.10	9.05	8.95
	WRDA, mL	91.5	91.5	91.5	91.5	91.5	91.5	91.5
	Darex AEA, mL	4.1	4.1	4.1	3.3	1.7	4.1	1.7
Test Results Fresh Concrete	Slump, mm	85	75	85	80	90	75	80
	Air Content, %	6.4	5.7	5.8	6.3	6.3	5.9	6.5
	Density, kg/m^3	2338	2352	2352	2345	2338	2345	2331
	Eff. w/c	0.380	0.394	0.387	0.385	0.389	0.387	0.382
	Cement kg/m^3	412	413	414	413	411	413	410
Compressive Strength, MPa	3d	32.8 33.1 33.0	32.3 31.7 32.0	30.8 31.3 31.1	32.6 33.4 33.0	31.1 30.5 30.8	28.8 27.7 28.3	27.3 27.3 27.3
	7d	33.8 33.8 33.8	33.2 33.9 33.6	34.9 35.4 35.2	35.6 36.0 35.8	33.3 32.9 33.1	32.9 33.1 33.0	30.8 30.2 30.5
	28d	41.2 43.5 42.4	41.2 40.6 40.9	43.3 42.2 42.8	43.7 43.7 43.7	39.6 39.1 39.4	42.3 42.2 42.3	38.3 39.3 38.8
	90d	50.9 50.8 50.9	49.8 50.8 50.3	48.9 50.0 49.5	51.5 54.4 52.9	49.0 44.5 46.8	51.5 50.6 51.1	47.6 45.6 47.1

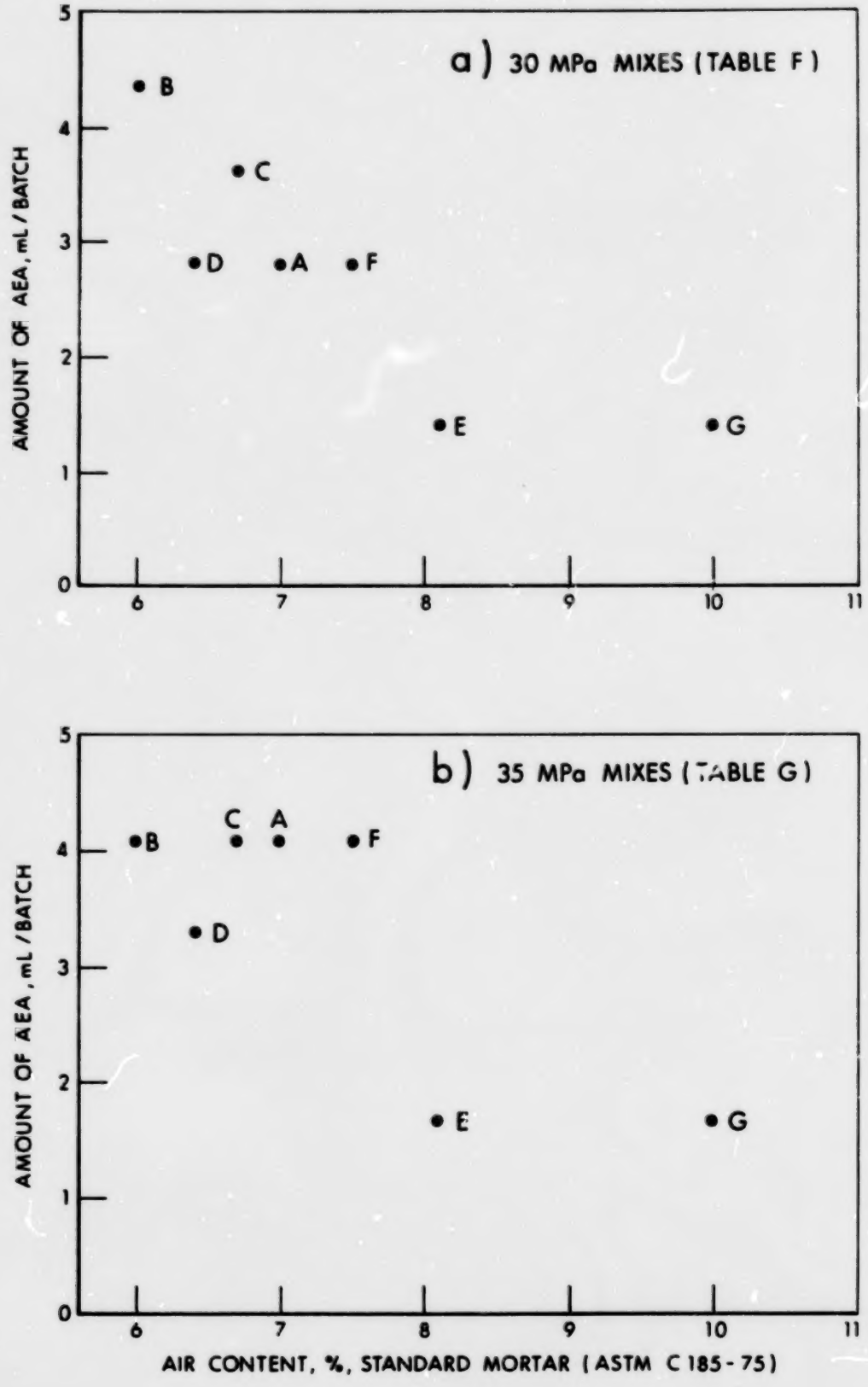

FIG. 1 - AMOUNT OF AIR-ENTRAINING ADMIXTURE PER BATCH vs AIR CONTENT OF STANDARD MORTAR

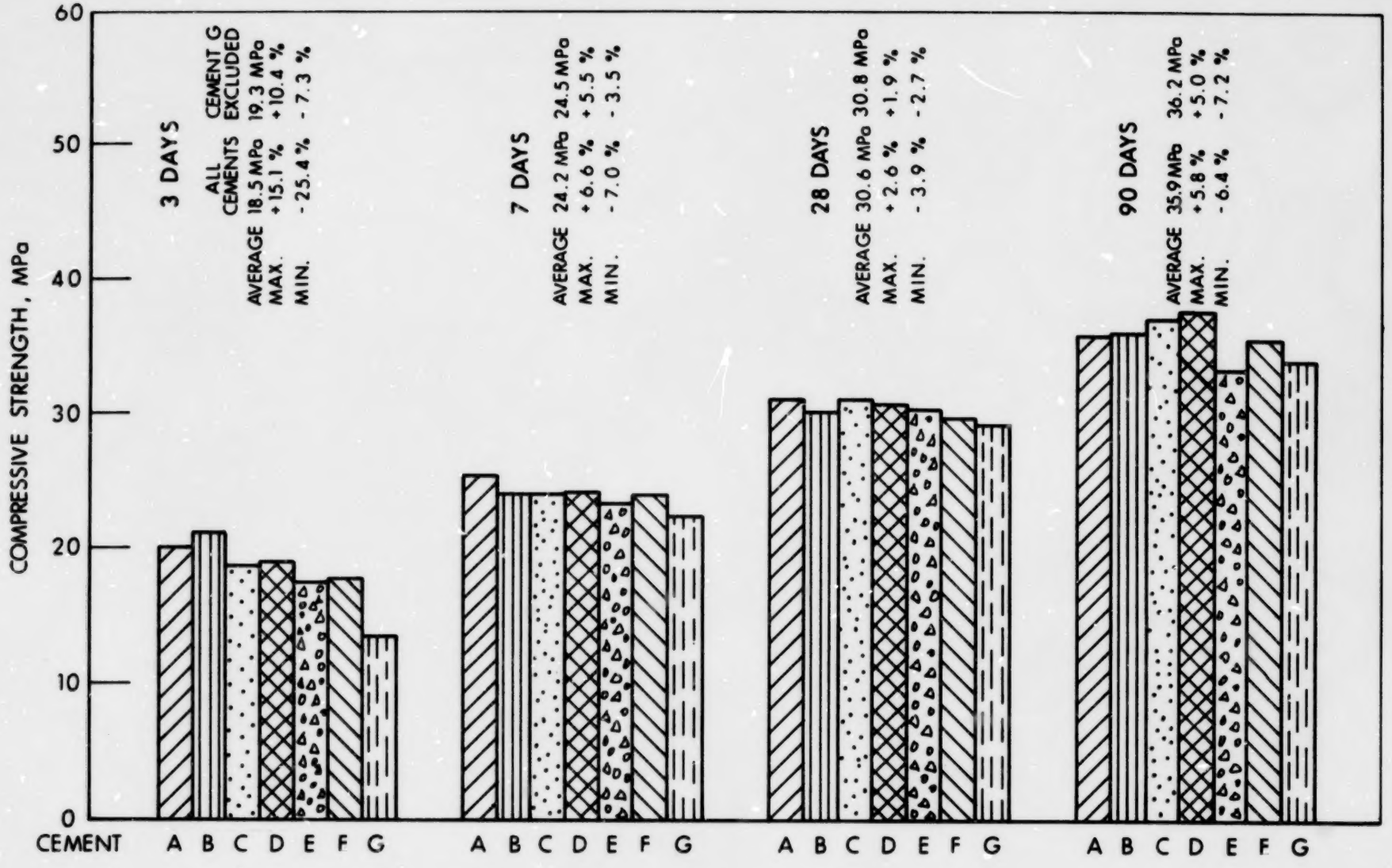

FIG. 2 - COMPRESSIVE STRENGTH, MPa
NON-AIR ENTRAINED, 20 MPa CLASS CONCRETE

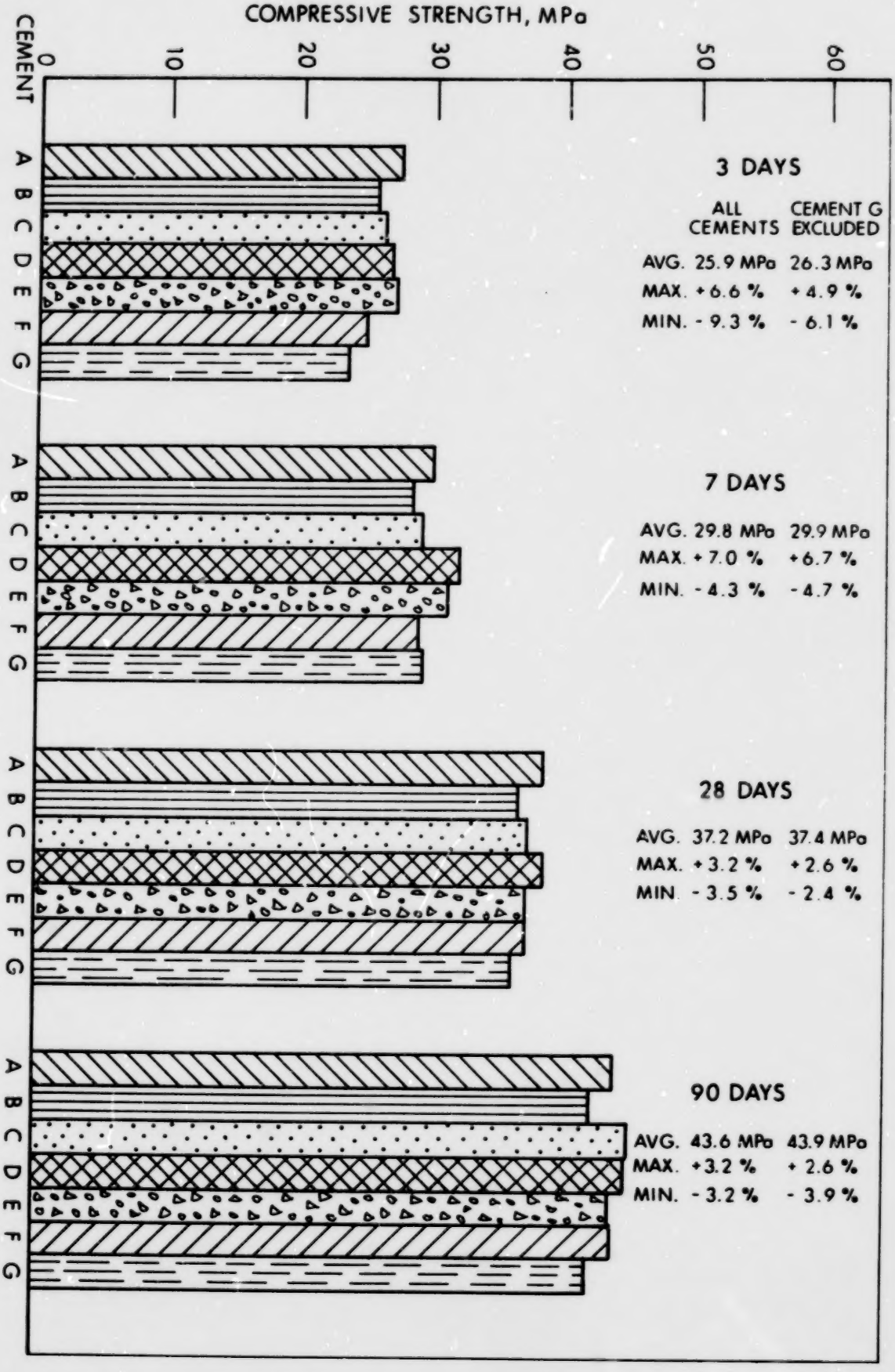

FIG. 3 - COMPRESSIVE STRENGTH, MPa
AIR ENTRAINED, 30 MPa CLASS CONCRETE

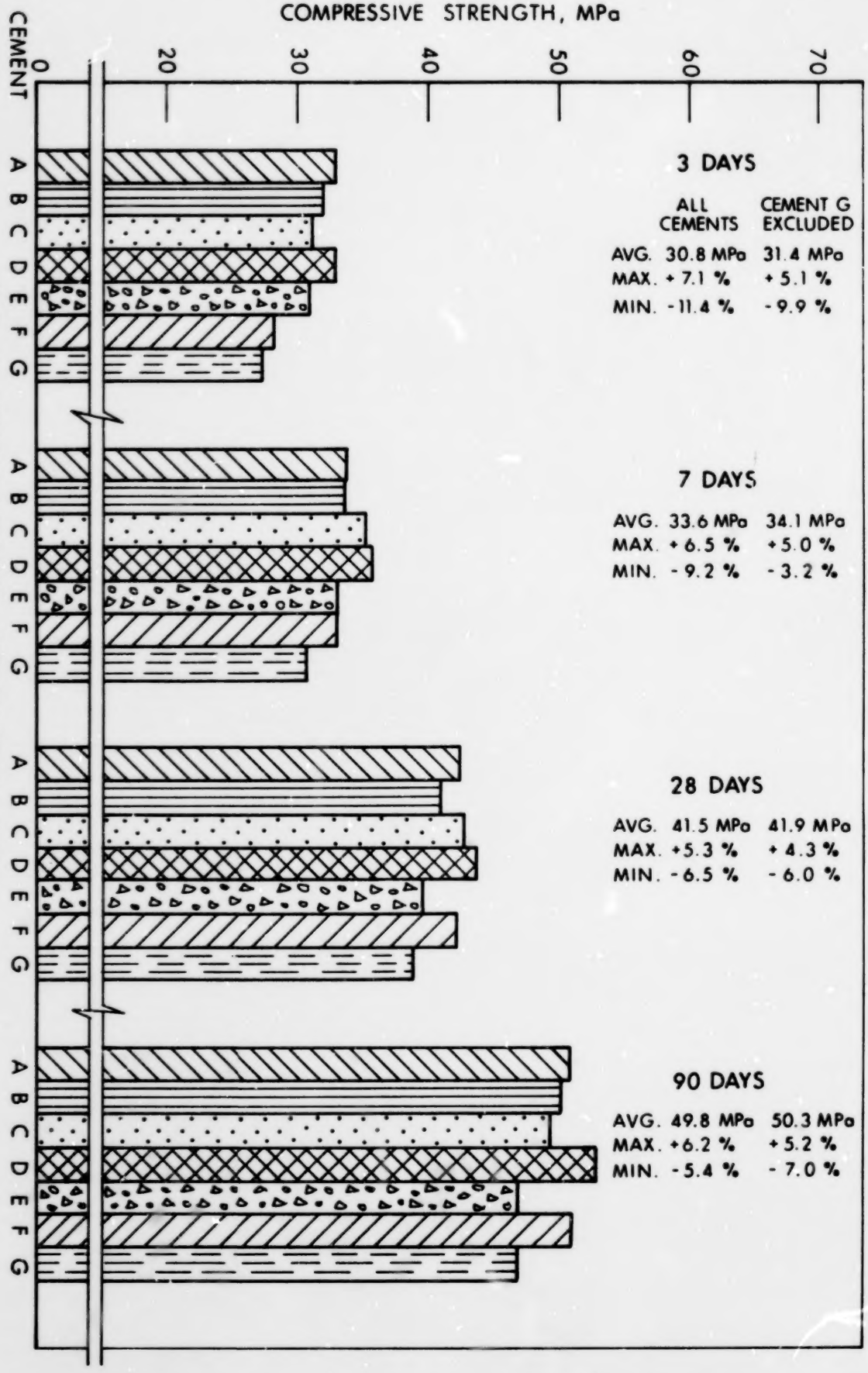

FIG. 4 - COMPRESSIVE STRENGTH, MPa
AIR ENTRAINED, 35 MPa CLASS CONCRETE

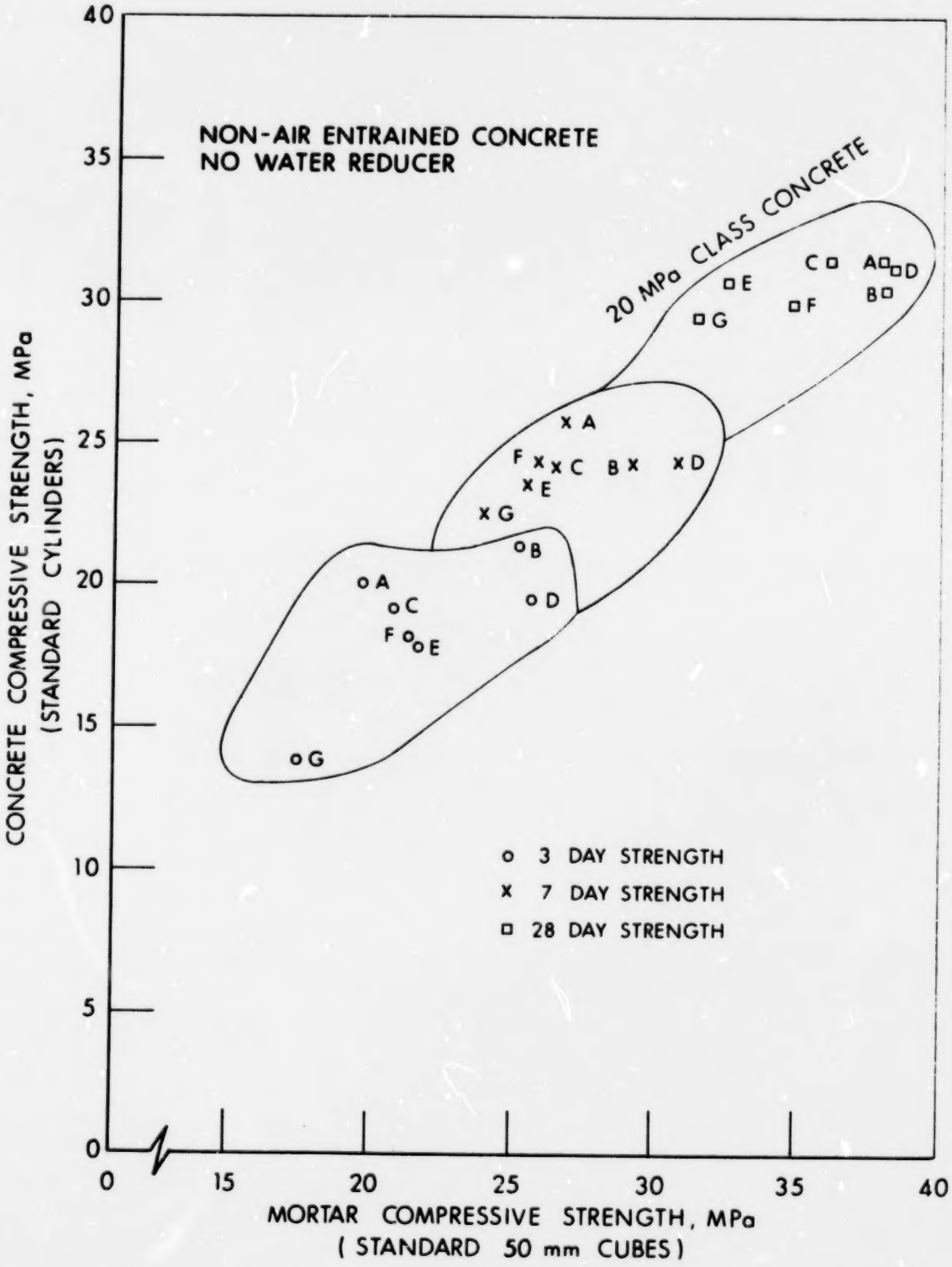

FIG. 5 - CONCRETE COMPRESSIVE STRENGTH vs STANDARD MORTAR COMPRESSIVE STRENGTH

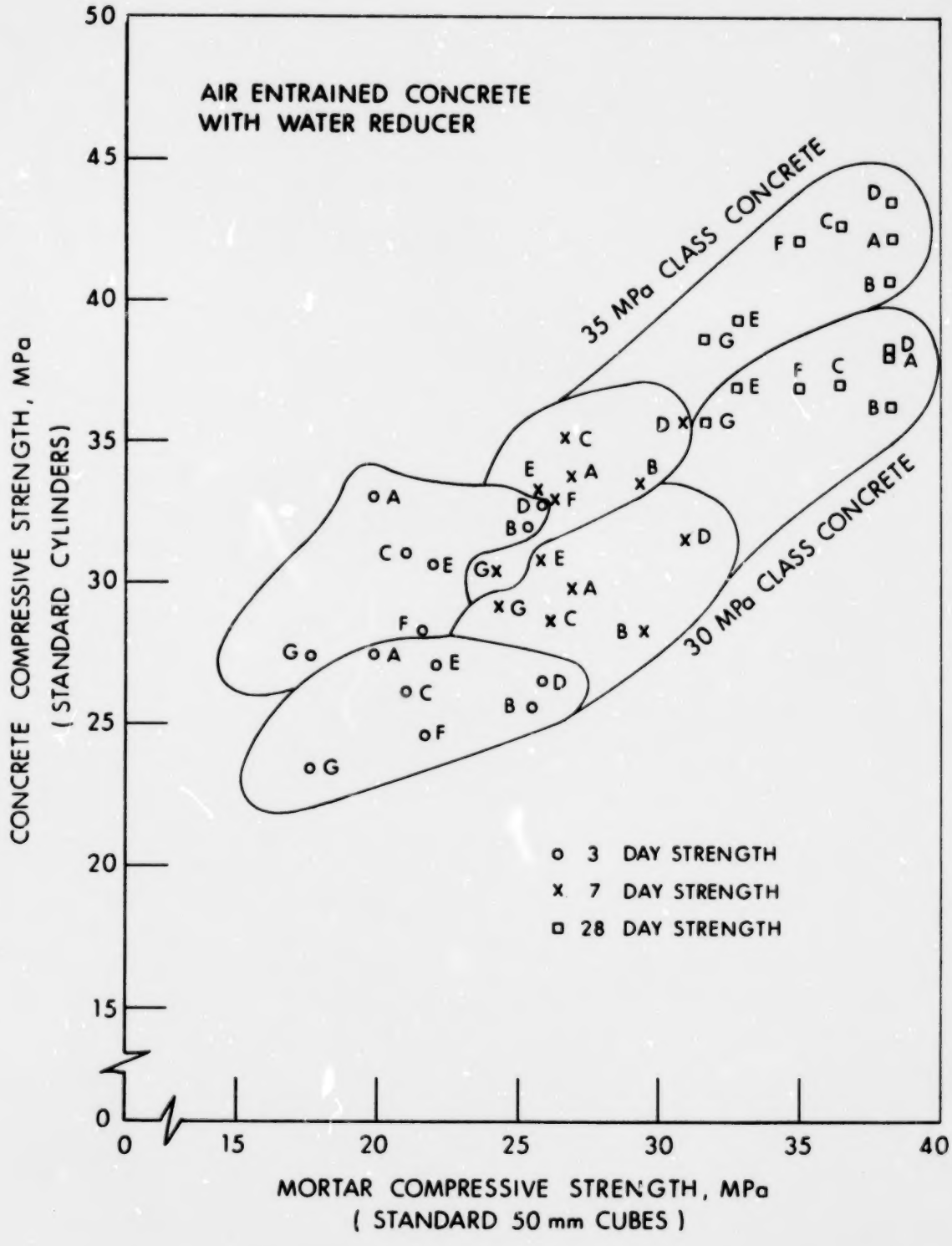

FIG. 6 - CONCRETE COMPRESSIVE STRENGTH vs STANDARD MORTAR COMPRESSIVE STRENGTH

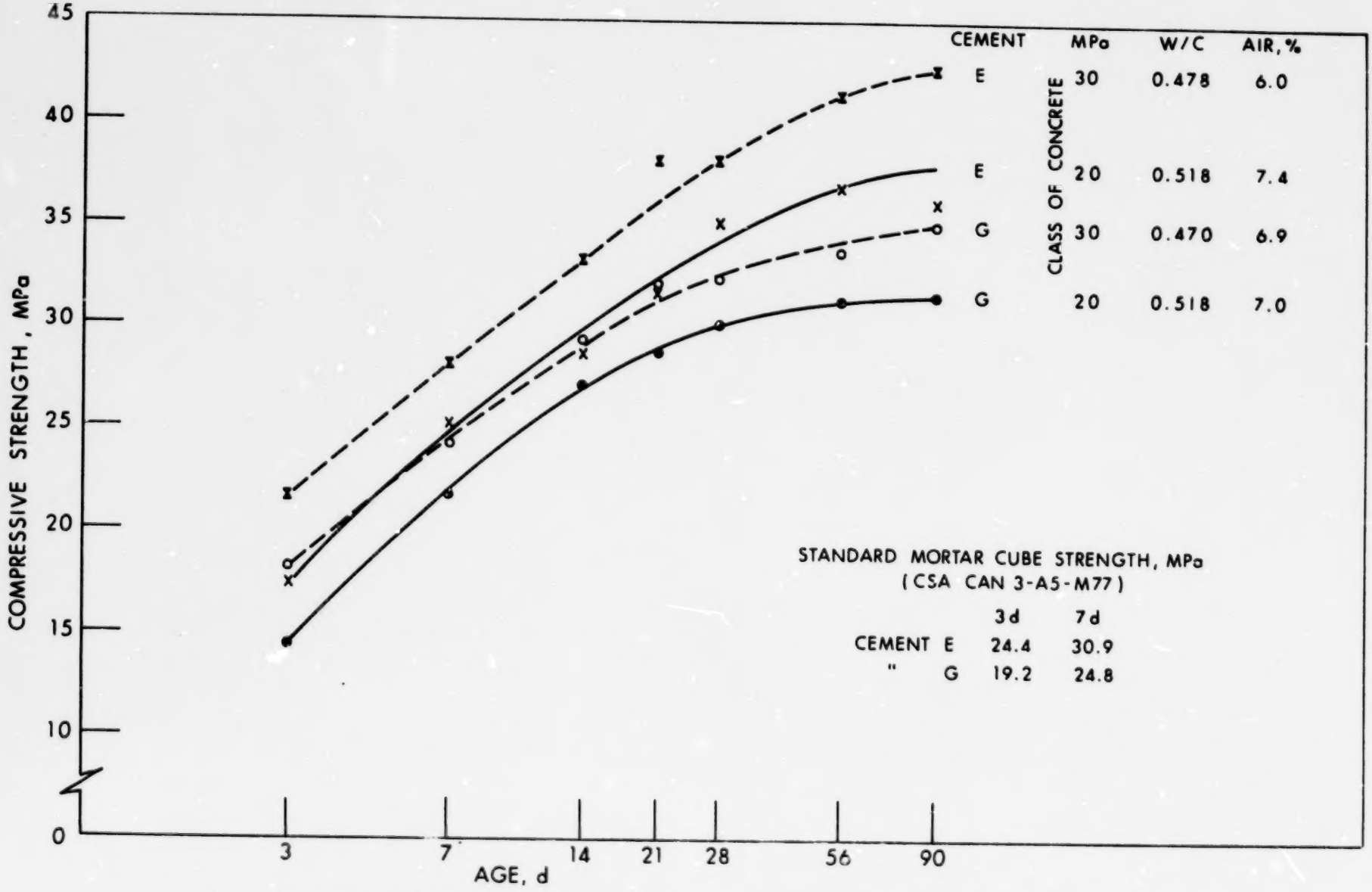

FIG. 7 - COMPRESSIVE STRENGTH vs AGE FOR CONCRETES MADE WITH CEMENT E AND G. TESTS BY NW REGION